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Morbidity of early spine surgery in the multiply injured patient

J. W. Galvin · B. A. Freedman · A. J. Schoenfeld · A. P. Cap · J. M. Mok

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Abstract
Introduction The optimal timing of surgery for multiply injured patients with operative spinal injuries remains unknown. The purported benefits of early intervention must be weighed against the morbidity of surgery in the early post-injury period. The performance of spine surgery in the Afghanistan theater permits analysis of the morbidity of early surgery on military casualties. The objective is to compare surgical morbidity of early spinal surgery in multiply injured patients versus stable patients.
Materials and methods Patients were retrospectively categorized as stable or borderline unstable depending on the presence of at least one of the following: ISS >40, ISS >20 and chest injury, exploratory laparotomy or thoracotomy, lactate >2.5 mEq/L, platelet <110,000/mm^3, or >10 U PRBCs transfused pre-operatively. Surgical morbidity, complications, and neurologic improvement between the two groups were compared retrospectively.
Results 30 casualties underwent 31 spine surgeries during a 12-month period. 16 of 30 patients met criteria indicating a borderline unstable patient. Although there were no significant differences in the procedures performed for stable and borderline unstable patients as measured by the Surgical Invasiveness Index (7.5 vs. 6.9, $p = 0.8$), borderline unstable patients had significantly higher operative time (4.3 vs. 3.0 h, $p = 0.01$), blood loss (1,372 vs. 366 mL, $p = 0.001$), PRBCs transfused intra-op (3.88 vs. 0.14 U, $p < 0.001$), and total PRBCs transfused in theater (10.18 vs. 0.31 U, $p < 0.001$).
Conclusions The results indicate that published criteria defining a borderline unstable patient may have a role in predicting increased morbidity of early spine surgery. The perceived benefits of early intervention should be weighed against the greater risks of performing extensive spinal surgeries on multiply injured patients in the early post-injury period, especially in the setting of combat trauma.

Keywords Combat spine trauma · Military casualties · Spine surgery in theater · Spine fracture · Polytrauma · Afghanistan war · Operation enduring freedom

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Introduction

Controversy exists as to the timing of spinal surgery in trauma patients with severe multisystem injuries. Advocates of early surgery cite the advantages of acute removal of compressive lesions on the neural elements, earlier mobilization, fewer complications and shortened hospital stay [1–3]. Proponents of delayed surgical decompression

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and stabilization report a more physiologically stable patient and avoidance of the “second hit” phenomenon resulting from an early prolonged surgical procedure [4].

Criteria used to categorize a trauma patient as physiologically stable or borderline unstable have been previously defined [5]. Patients deemed borderline unstable have been shown to be at increased risk of complications following prolonged surgeries in the early post-injury period [6, 7]. These criteria have clinical importance by indicating a delayed surgical approach to definitive fixation in pelvic and extremity trauma to allow physiologic stabilization in the intensive care unit and avoid the systemic inflammatory response syndrome (SIRS) [5]. There is a paucity of literature that examines the potential role of such criteria in the management of spinal trauma.

The current wars in Afghanistan and Iraq have introduced a unique cohort of patients with spine injuries. The incidence of spinal trauma sustained by military personnel is higher than that reported in previous conflicts [8]. Military spinal trauma patients sustain complex multisystem trauma from their battlefield wounds [9, 10]. Many meet criteria designating a borderline unstable patient [5].

The performance of spine surgery in the Afghanistan theater permits analysis of the morbidity of early surgery on military casualties. The objective of this performance improvement project is to compare the surgical morbidity of definitive spinal surgery in theater in stable patients and in patients meeting criteria indicating a borderline unstable patient. This is a retrospective analysis; the borderline unstable criteria were not used as part of a protocol to determine care of spinal injuries in these patients.

Materials and methods

Following review and approval from the Joint Combat Casualty Research Team (JC2RT) United States Central Command Human Protections Administrator, we conducted a process improvement project to retrospectively evaluate spinal surgeries performed in theater. The cohort consisted of soldiers from the United States or North Atlantic Treaty Organization (NATO) nations who underwent spinal surgery in theater. All spinal surgeries performed for traumatic injuries during a 12-month period within the American military health system in Afghanistan were identified. Spinal surgery was defined as decompression and/or instrumentation for the purposes of this analysis; surgery limited to debridement of open spinal wounds was not included.

The cohort was organized into two categories (“borderline unstable” and “stable”) based on the following clinical criteria, which were adopted from previously described criteria to indicate a damage control approach to pelvic and extremity trauma: injury severity score (ISS) > 40, ISS > 20 and chest injury, exploratory laparotomy or thoracotomy, pre-operative lactate >2.5 mEq/L, pre-operative platelets (PLT) $<110{,}000/\text{mm}^3$, >10 U packed red blood cells (PRBCs) transfused pre-operatively [5]. Patients meeting one or more criteria were designated “Borderline Unstable” patients. Patients not meeting the above criteria were designated “Stable” patients for the purpose of this project.

Information for the cohort was abstracted from the patient’s medical record. Age, date of injury, mechanism, and Glasgow Coma Scale (GCS) upon presentation were recorded. ISS was obtained via query of the Joint Theater Trauma Registry for each patient; all other data were obtained from primary source documents. Presence of any intra-cranial injury or a chest injury was identified by review of the trauma computed tomography (CT) scan radiology report. Hemoglobin (Hb), PLT, and lactate were obtained from the pre-operative laboratory test immediately before surgery.

The anatomic location of the injury was determined by inspection of the pre- and/or post-operative CT scan images. Neurologic status was determined by review of primary source documents. If a note indicated a clear diagnosis (e.g., “cauda equina syndrome”), this was recorded as the neurologic status. Weakness was considered present if documented in any note, even in the presence of concomitant extremity injuries, with the understanding that this may overestimate the proportion of patients determined to have a neurologic injury. Neurological status was graded according to the American Spinal Injury Association (ASIA) Impairment Scale for injuries at L2 and above. For injuries at L3 and below, neurological status was assigned a grade reflective of their function similar to ASIA (full motor and sensation, motor function $\geq 3/5$, motor function $<3/5$, no motor function with intact sensation, no motor or sensation). Analysis of injury morphology and indications for surgery was not performed due to the potential for variability in interpretation. Change in neurologic status following surgery was determined by comparison of pre- and post-operative notes. Neurologic status was considered improved if the doctor’s note concluded there was an improvement or if a graded-motor examination suggested improved strength, with the understanding that this may overestimate the proportion of patients determined as improved.

The number of units of PRBCs transfused during the spine portion of the case and the total units transfused in theater were recorded by review of the anesthesia and transfusion records.

Due to difficulties in determining the exact time of injury, time to initial surgical intervention was calculated based on calendar dates. Operative times and estimated blood loss (EBL) were obtained by inspection of the

Table 1 Cohort characteristics

	Mean (median)	Range
Age (years)	27.6 (25.9)	(19.3, 47.3)
ISS	26.1 (26.5)	(9, 43)
GCS	12.8 (15)	(3T, 15)
	n	%
Total	30	100
Mechanism of injury		
Blast	21	70 %
Gunshot wound	3	10 %
Fall from height	2	7 %
Motor vehicle accident	2	7 %
Other	2	7 %
Intubated at presentation	6	20 %
Brain injury*	6	20 %
Borderline unstable criteria present**	16	53 %
ISS >40	2	7 %
ISS >20 and chest trauma	9	30 %
Exploratory laparotomy	8	27 %
Lactate > 2.5 mEq/L	6	20 %
Platelet <110,000/mm^3	4	13 %
10 U PRBCs pre-spine surgery	4	13 %

ISS injury severity score, *GCS* Glasgow coma scale, *PRBCs* packed red blood cells, *T+* intubated

* Includes if GCS <15T (intubated) without documentation of normal head CT

** Number of patients with at least one criterion; a patient could meet more than one criterion

anesthesia record. If a patient underwent multiple procedures, then the blood loss recorded for the spine portion only was determined. In addition, a second method was utilized to estimate blood loss based on pre- and post-operative Hb, determined using the time stamp [11]. This calculation provides the amount of blood loss as a percentage of total blood volume. Surgical characteristics were determined from the surgeon's operative note or, if not available, the post-operative CT scan. The spine Surgical Invasiveness Index was calculated for each surgery [12]. This is a validated instrument that accounts for approach, number of levels, and decompression, instrumentation, and fusion, with higher surgical invasiveness index predictive of increased blood loss, operative time, and infection. The follow-up period ended upon medical evacuation out of theater to Landstuhl Regional Medical Center (Landstuhl, Germany).

Differences in neurologic improvement, surgical morbidity, and complications were determined between borderline unstable and stable patients. Categorical variables were evaluated with the Chi-square statistic. The Fisher's exact test was utilized for categorical variables if frequency was less than five. Continuous variables were compared using the Mann–Whitney test for non-parametric data. Statistical significance was defined as $p < 0.05$.

Results

During this period, 30 military casualties underwent 31 spinal surgeries in theater. All were male American or NATO military personnel. Mean age was 27.6 ± 6.5 (range 19.3–47.3). Mean ISS was 26.1 ± 8.7 (9–43). 26 sustained their injury during combat operations (Table 1). One patient underwent two spine surgeries.

Spine surgery was performed within a mean of 0.8 days of injury. The spine operation was performed on the same or next day of injury for 27 of the 30 (90 %) patients.

Of the 31 spine surgeries, 17 involved 16 patients meeting at least one criterion indicating a borderline unstable patient. (Table 1) The remaining 14 patients were considered stable patients. Among the 16 borderline unstable patients, two had ISS >40, nine had ISS >20 and a concomitant chest injury, eight had previous exploratory laparotomy, six had lactate >2.5 mEq/L, and four had PLT <110,000/mm^3. Four borderline unstable patients received 10 or greater units of PRBCs preceding the spine surgery.

The anatomic level of the vertebral column injury requiring operative intervention was L2 or above (spinal cord level) in 19 (63 %) patients, of whom 7 (37 %) had documented profound neurologic deficits (ASIA A-C). The anatomic level requiring operative intervention was L3 or below in the remaining 11 (37 %) cases, of which 6 (54 %) had documented profound neurologic deficits (motor strength less than 3/5). An apparent spinal cord injury, conus medullaris/cauda equina syndrome was considered present in 12 (40 %) of the 30 patients in this study: among borderline unstable patients, 5 (31 %) had apparent spinal cord injury or conus medullaris/cauda equina syndrome, compared with seven (50 %) among stable patients ($p = 0.3$).

All except one surgery (an anterior cervical fusion) was performed via a posterior approach. The lumbar spine was the most operated area ($n = 15$), followed by thoracolumbar ($n = 8$), thoracic ($n = 3$), lumbosacral ($n = 3$), and cervicothoracic ($n = 2$). Instrumentation was performed in 24 (77 %) of the cases. Mean number of levels operated was 3.4 ± 1.3. The mean Surgical Invasiveness Index was 7.2 ± 3.5. Mean operative time for the spine surgery was 3.7 h. Mean EBL from the anesthesia record was 902.5 mL (median 575), with a wide range noted (50 mL to 4 L). Eight (27 %) cases had EBL exceeding

Table 2 Surgery characteristics

	Borderline unstable ($n = 17$)*	Stable ($n = 14$)	p value
Surgical invasiveness index	7.5 ± 3.6 (7)	6.9 ± 3.4 (8)	0.8
Instrumentation used	14	10	0.67
Operative time (h)	4.3 ± 1.5 (3.9)	3.0 ± 0.8 (3.0)	0.01
EBL (mL)	1,372 ± 1,216 (700)	366 ± 238 (350)	0.001
Calculated blood loss (% body volume)	28 ± 23 (24)	22 ± 11 (23)	0.67
PRBCs transfused intra-op (U)	3.9 ± 2.8 (3.5)	0.1 ± 0.5 (0)	<0.001
PRBCs transfused intra- and post-op (U)	4.4 ± 2.7 (4)	0.3 ± 1.1 (0)	<0.001

Mean ± standard deviation (median)

EBL estimated blood loss, *PRBCs* packed red blood cells; *intra-op* intra-operative, *post-op* post-operative

* 17 surgeries performed on 16 patients in borderline unstable group

750 mL and four (13 %) cases had EBL exceeding 1,500 mL. Mean blood loss calculated from pre- and post-operative Hb was 25 % of total blood volume (median 24, interquartile range 26). Ten (33 %) cases had calculated blood loss exceeding 30 % of total blood volume. Mean number of PRBCs transfused during the spine surgery was 2.1 U; in patients with EBL greater than 750 mL, it was 4.75 U.

Comparing borderline unstable patients and stable patients, there was no significant difference in Surgical Invasiveness Index (Table 2). Borderline unstable patients had significantly higher operative time, estimated blood loss, units of PRBCs transfused intra-operatively, units of PRBCs transfused intra- and post-operatively, and total units of PRBCs transfused in theater (10.2 vs. 0.3 U, $p < 0.001$). Borderline unstable patients had significantly lower pre- (11.0 vs. 13.8 g/dL, $p = 0.001$) and post-operative Hb (10.0 vs. 11.1 g/dL, $p < 0.05$). There was no significant difference in calculated blood loss.

An improvement in neurologic status, including spinal cord injury, conus medullaris/cauda equina syndrome, or nerve root injury, was considered present after 2 of 17 (12 %) borderline unstable cases with any neurologic deficit, as opposed to 5 of 12 (42 %) stable cases with any neurologic deficit ($p = 0.09$), (Table 3). Borderline unstable patients had higher proportions remaining intubated at transfer or in whom a complication was documented, although none of these differences were statistically significant. There was no significant difference in time of transfer between borderline unstable and stable patients (2.7 vs. 2.4 days, $p = 0.3$).

Table 3 Neurologic outcomes and complications

	Borderline unstable ($n = 16$)		Stable ($n = 14$)		p value
Neurologic improvement					
Any deficit	2	12 %	5	42 %	0.09
SCI or CES only	1	20 %	3	43 %	0.6
Complication	5	31 %	3	21 %	0.7
Pressure ulcer	2		3		
Pneumonia	1		0		
DVT	2		0		
Intubated during transport	10	63 %	6	43 %	0.3

SCI spinal cord injury, *CES* cauda equina syndrome, *DVT* deep vein thrombosis

Discussion

The results demonstrate that early definitive spine surgery can represent a considerable physiologic insult to multiply injured patients, which are a group considered at risk for serious complications. Median operative time was nearly 4 h and median EBL was 700 mL in the borderline unstable group. All patients in the cohort underwent spine surgery within 4 days of injury, a period at risk for inciting SIRS. Although the surgical characteristics were similar (as measured by Surgical Invasiveness Index), spine surgeries performed on borderline unstable patients had longer operative times, higher blood loss, and higher transfusion requirements. This is not surprising considering that many were likely coagulopathic due to massive transfusion or thrombocytopenia or not fully resuscitated. Compared to stable patients, the borderline unstable patients had a higher rate of complications and higher proportion of patients intubated during transport, though none of these differences were statistically significant. The observed differences in operative and peri-operative morbidity are also likely due in part to casualties' concomitant non-spinal injuries.

Patients meeting criteria indicating a borderline unstable patient in this cohort were indeed seriously wounded; included in this group are eight patients who underwent exploratory laparotomy and four who received massive transfusions before their spinal operation. This military cohort sustained spinal injuries due to mechanisms of very high energy, 70 % being wounded by a blast, and nearly half displayed profound neurologic deficits at presentation. The proportion of patients with spinal cord injury or conus medullaris/cauda equina syndrome was not higher than the Stable patients, so the results do not indicate that the borderline unstable patients had more urgent spinal problems necessitating interventions in theater.

The criteria indicating a borderline unstable patient utilized in this analysis were adopted from Pape et al., who identified certain variables to be independent risk factors for adverse outcomes after trauma, such as acute respiratory distress syndrome (ARDS), multi-organ failure, and death [5, 13–18]. The criteria have been used to select patients appropriate for a damage control approach to their injuries [7, 19–21]. "Damage Control surgery" was first adopted by trauma surgeons to describe initial control of penetrating abdominal injuries with exploratory laparotomy and packing, followed by resuscitation in an intensive care setting, and later return to the operating room for definitive surgical treatment [22]. Its success led to application of the same principles to orthopaedic injuries [6, 19]. The goal is to avoid the second physiologic insult caused by large surgical interventions during the early post-traumatic inflammatory period. The so-called "second hit" may lead to SIRS, which is a hyper-inflammatory reaction with potentially disastrous consequences including multiple organ failure [23].

United States service members wounded in battle in the Iraq and Afghanistan theaters have unprecedentedly high rates of survival due to advances in personal protective equipment, vehicle technology, and access to medical care [24, 25]. A guiding principle of the management of casualties in theater is damage control, consisting of initial stabilization of life and limb-threatening wounds, rapid aeromedical evacuation, and deferment of definitive treatment to facilities later in the evacuation chain [26, 27]. Casualties are now transported with unprecedented speed out of theater to an American College of Surgeons level 1 trauma center (Landstuhl Regional Medical Center). The approach has been highly successful; combat casualties surviving their initial wounds and evacuated to a medical facility have survivability exceeding 90 % [24, 28].

Traumatic spinal injuries represent a unique category of injury. The presence of a neurologic deficit and/or instability lends urgency to the timing of management [29–31]. While the goals of surgical intervention may be clear, the morbidity of spine surgery, especially in the seriously injured, has not been well described. Some authors have advocated early stabilization and decompression of spinal injuries in polytrauma patients as safe with superior outcomes compared to delayed surgery, although this remains somewhat controversial [2, 32, 33]. A recent retrospective study reported significantly higher mortality (23 vs. 13 %) in seriously injured patients who underwent definitive spinal surgery within 72 h of injury when compared to late surgery, despite no detectable differences in patient, injury, or surgery characteristics [34].

The patients in this cohort underwent early definitive open surgery for their spinal injuries, which should be differentiated from "Spine Damage Control" surgery. This relatively novel idea in the treatment of spinal trauma advocates early (<24 h) limited posterior instrumentation of unstable thoracolumbar injuries in polytrauma patients, followed by definitive decompression and fusion after physiologic stabilization [35]. Compared to an approach of delayed definitive surgery, this approach was reported to result in significantly lower number of ventilator dependent days, in-patient hospitalization days, and complications [2].

In addition to limitations inherent to retrospective analyses, the scope of this approved performance improvement project was limited to evaluation of immediate surgical morbidity with lack of analysis of longer term outcomes. The period under examination lasted up to the patient's evacuation from theater, which limits the ability to assess overall neurologic outcome and later complications. Comparison of outcomes of our cohort with casualties who sustained similar injuries and did not undergo surgery would further inform the risk–benefit analysis of early spine surgery in theater. Despite review of all available primary source documents including multiple echelons of care, in many cases a detailed objective neurologic exam was not documented, and a neurologic status was determined by the cumulative subjective assessments of multiple providers. For reasons described in the methods, the results likely overestimate the proportions of patients with neurologic deficit and improvement. The post-operative neurologic examinations were performed shortly after injury and, therefore, have doubtful value as predictors of final outcome [36]. The size of the cohort also limited the ability to detect statistically significant differences between groups. Finally, an important limitation is that the cohort consisted of military personnel who were young healthy men subjected to injury mechanisms of extremely high energy, which may limit applicability in the civilian setting.

Conclusions

This performance improvement project, although limited in scope, indicates that established criteria indicating a borderline unstable patient may have a role in predicting morbidity of early spine surgery. It also presents the short term outcomes of a unique cohort of military casualties who underwent spinal surgery in a combat theater under the constraints of limited resources and an austere environment. The perceived benefits of early intervention, extrapolated from a civilian experience with important differences from combat trauma, should be weighed against the greater risks of performing extensive spinal surgeries on patients meeting criteria indicating a borderline unstable patient. The Joint Theater Trauma System Clinical Practice Guideline for spinal trauma states that surgery may be considered in theater in the setting of progressive neurologic deficit, open cerebrospinal fluid leak, or gross instability [37]. We advocate that surgical intervention in a combat theater should largely be limited to the most exigent circumstances in the setting of clinically important and progressive neurological deficit with demonstrable spinal canal stenosis due to fracture fragment, disc herniation, or epidural hematoma. A potential approach to spinal trauma in theater in borderline unstable patients is decompression of compressive lesions to limit the morbidity of early surgery, followed by appropriate external spinal immobilization and rapid aeromedical evacuation to a tertiary care facility for definitive stabilization.

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Conflict of interest Drs. Galvin, Cap, and Freedman are employees of the United States Army. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of Defense or the United States government.

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